Plasmon-assisted Phase Transition of VO_2

Wakana KUBO[1], Takuo TANAKA [2]

[1] Tokyo University of Agriculture and Technology, [2] Metamaterials Laboratory, RIKEN
E-mail:w-kubo@cc.tuat.ac.jp

Vanadium dioxide (VO_2) exhibits a thermally driven metal-to-insulator phase transition, which accompany drastic changes in resistivity and opacity between metal and insulator phases. In addition to a noticeable transmission change in IR region, VO_2 phase transition induces a sharp divergent bulk permittivity around the phase transition temperature, leading to the interest in the research on VO_2 surged with the emergence of plasmonics and metamaterials.[1]

Here we investigate the interaction between plasmons and VO_2, that is, in-situ and reversible tuning in material properties of VO_2 by plasmons. It is commonly believed that the phase transition temperature of a material is an intrinsic property determined by its chemical composition and the crystal structure. Based on this argument, the most straightforward method to alter the phase transition temperature is to introduce dopant into the material. However, such change is neither in-situ controllable nor reversible, as the phase transition temperature is dictated by the crystal status controlled by doping. In this work, we observed plasmon-assisted phase transition by embedding gold nanorods (NRs) into VO_2 and realized different transition temperatures by changing Au NRs densities.

Au NR arrays were fabricated by electron beam lithography and Au deposition. Au NR arrays were completely covered with metal vanadium film, followed by annealing at 440 ºC, resulting in a VO_2 film embedding Au NR arrays. (VO_2-Au NRs)

Transmission spectra with various temperatures were measured under polarized IR light. And the phase transition temperature (T_{phase}) of VO_2-Au NRs was calculated from a hysteresis curve obtained from measured transmission spectra. In this experimental setup, only long-axis polarization of Au NR can excite localized surface plasmon resonance (LSPR) since the incident light involves only IR light and the short-axis LSPR of the Au NRs lies in the visible light region. That means plasmon excitation and non-excitation can be switched just by changing polarization directions, leading to the elucidation of the LSPR contribution on VO_2 phase transition.

As a result, T_{phase} of VO_2 which does not include Au NRs was (49.0 ± 0.0) ºC (n=3) under both polarizations. The T_{phase} of Au-NRs under long-axis polarization, with LSPR excitation, was (45.7 ± 0.1) ºC (n=3), while T_{phase} under short-axis polarization with non-LSPR excitation was (49.0 ± 0.0) ºC (n=3), resulting in the differential T_{phase} of 3.3 ºC. Since these T_{phase} were measured at the same sample location, and only polarization directions were changed, we concluded that LSPR of Au NRs assisted VO_2 phase transition.

In addition, the density dependence of Au NRs on VO_2 phase transition was examined. The density of Au NRs was controlled from 0 to 17% by tuning pitches between Au NRs. The density of Au NRs of 0% indicates a bare VO_2 film does not include Au NRs. The ΔT_{Phase} of the bare VO_2 was 0, meaning that its T_{phase} did not change at all under both polarizations. On the other hand, an increase of ΔT_{Phase} was clearly observed as area densities of Au NRs increased as shown in Fig. 1.

Possible mechanisms are discussed. There are several possibilities accountable for plasmon-assisted VO_2 phase transition. Local heating effect of plasmonic nanostructure is one of the possibilities, which is caused by an internal decay of hot electrons inside a metal nanostructure, resulting in a significant heating of the nanostructure and its surrounding media through electron-electron and electron-phonon scattering relaxation processes. In addition, a direct injection of hot electrons into VO_2 accompanied with LSPR excitation is also undeniable as reported by Appavoo, et al.[2]

In summary, obvious decrease in T_{phase} of VO_2 under LSPR excitation was observed compared to that measured under LSPR non-excitation at the same sample location, indicating the LSPR of Au NRs assisted VO_2 phase transition.

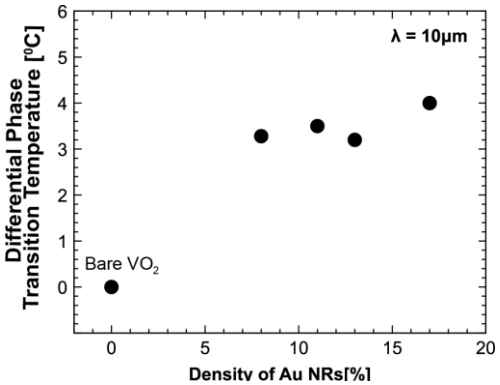

Fig. 1 Differential phase transition temperature (ΔT_{Phase}) as a function of Au NRs area densities.

References

1. Driscoll, T.; Kim, H.-T.; Chae, B.-G.; Kim, B.-J.; Lee, Y.-W.; Jokerst, N. M.; Palit, S.; Smith, D. R.; Di Ventra, M.; Basov, D. N. *Science* **2009,** 325, (5947), 1518-1521.

2. Appavoo, K.; Wang, B.; Brady, N. F.; Seo, M.; Nag, J.; Prasankumar, R. P.; Hilton, D. J.; Pantelides, S. T.; Haglund, R. F. *Nano Lett.* **2014,** 14, (3), 1127-1133.